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Pietro Ubertini on behalf of the IBIS Survey Team

The INTEGRAL - HESS/MAGIC connection: a new class of cosmic high energy accelerators from keV to TeV

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Abstract The recent completion and operation of the High Energy Stereoscopic System [1], an array of ground based imaging Cherenkov telescopes, has provided a survey with unprecedented sensitivity of the inner part of the Galaxy and revealed a new population of very high energy gamma-rays sources emitting at E>100 GeV. Most of them were reported to have no known radio or X-ray counterpart and hypothesised to be representative of a new class of dark nucleonic cosmic sources. In fact, very high energy gamma-rays with energies E $> 10^{11}$ eV are the best proof of non-thermal processes in the universe and provide a direct in-site view of matter-radiation interaction at energies by far greater than producible in ground accelerators. At lower energy INTEGRAL has regularly observed the entire galactic plane during the first 1000 day in orbit providing a survey in the 20-100 keV range resulted in a soft gamma-ray sky populated with more than 200 sources, most of them being galactic binaries, either BHC or NS [5]. Very recently, the INTEGRAL new source IGR J18135-1751 has been identified as the soft gamma-ray counterpart of HESS J1813-178 [18] and AXJ1838.0-0655 as the X/gamma-ray counterpart of HESS J1837-069 [14].

Detection of non thermal radio, X and gamma-ray emission from these TeV sources is very important to discriminate between various emitting scenarios and, in turn, to fully understand their nature.

The implications of these new findings in the high energy Galactic population will be addressed.

Keywords gamma-ray sources · high energy emission processes

P. Ubertini
Istituto di Astrofisica Spaziale e Fisica Cosmica (IASF), Roma, Italy
Tel.: +39 06 49934090
Fax: +39 06 49934094
E-mail: pietro.ubertini@iasf-roma.inaf.it

1 Introduction

HESS (High Energy Stereoscopic System), a ground-based Cerenkov array telescopes has been operated since a few years and in 2004 has performed the first Galactic plane scan with a sensitivity of a few percent of the Crab at energies above 100 GeV, resulting in the discovery of eight sources, most of which without any counterpart at different energies [1,2]. Particular attention was devoted to HESS J1813-178, not identified with any known X/gamma ray emitter and hypothesised to be a dark particle accelerator. Independently, and at the same time, INTEGRAL discovered a new soft gamma-ray source, namely IGR J18135-1751, identified as the counterpart of HESS J1813-178. This high energy emitter, whose nature was still mysterious at the time of the discovery was then associated with the supernova remnant (SNR) G12.82_0.02 [18,6,10]. Even if a chance coincidence cannot be completely ruled out in view of the 2 arcmin INTEGRAL error box and the possible angular extension in the high energy, the overall characteristics of this star forming region [7] comprising SNR G12.82_0.02 are consistent with supernova/plerion origin. More recently, the MAGIC (Major Atmospheric Gamma Imaging Cerenkov telescope) collaboration has reported a positive observations of HESS J1813-178, resulting in a gamma-ray flux consistent with the previous HESS detection and showing a hard power law with $\alpha = 2.1$ in the range from 0.4-10 TeV [3].
The detection of a substantial number of very high energy Galactic sources emitting a large fraction of energy in the GeV to TeV range has opened a new space window for astrophysical studies related to cosmic particle acceleration. Different types of Galactic sources are known to be cosmic particle accelerators and potential sources of high energy gamma rays: isolated pulsars/pulsar wind nebulae (PWN), Supernova remnants, star forming regions, binary systems with a collapsed object like a microquasar or a pulsar etc. The HESS detection of several TeV emitters without any counterpart at different energy has made the detection of X and gamma-ray emission from these sources a key issue to disentangle the mechanisms active in the different emitting regions and, in turn, to understand the source nature. The IBIS gamma-ray imager on board INTEGRAL is a powerful tool to search for their counterpart above 20 keV in view of the arcmin Point Source Location Accuracy associated to $\sim$ mCrab sensitivity for exposure >1Ms [17].

2 HESS J1837-069=AXJ1838.0-0655: the first IBIS/HESS new source

AXJ1838.0-0655is located in the Scutum arm region and has been detected as a new INTEGRAL source by [15] and [5] and it is detected by IBIS up to 300 keV with a high statistical significance, exceeding 15σ. The best positional location is R.A.(2000) = 18h 38m 01.7s and Dec = -06° 54' 14.4" with an error radius uncertainty of ≤3' [14]. The IBIS data provide a good fit with a simple power law with a resulting χ^2_ν/dof=0.3/5 with a photon index Γ=1.66±0.23 (90% c.l) and a 20-300 keV flux of 9×10^{-11} erg cm^{-2} s^{-1} [14]. HESS J1837-069 is one of the 10 very high energy sources located in the central part of

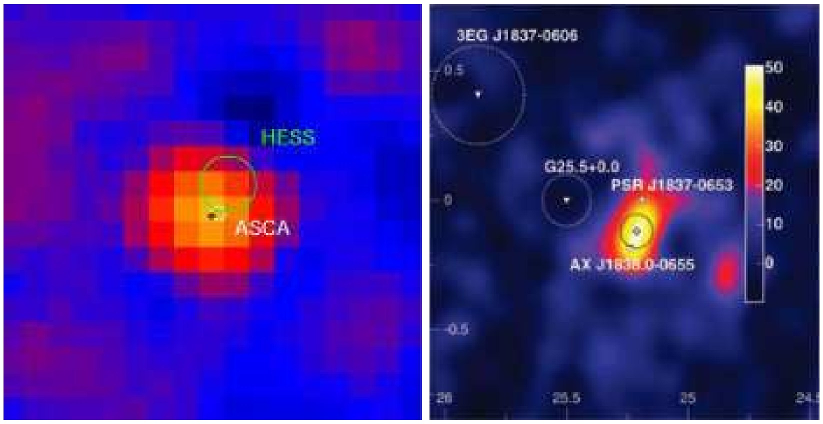

Fig. 1 Left panel: from Malizia et al. 2005. The IBIS/ISGRI 20-300 keV significance map showing the location of AX J1838.0-0655 as well as the position and extension of HESS J1837-069 (white circle) and the Einstein position (black cross). The position and uncertainty of the ASCA source is basically coincident with the central, brightest IBIS pixel. Right panel: from Aharonian et al. 2005. The emission region of HESS J1837-069 overlapped to the ASCA error box of AXJ1838.0-0655. As can be seen even if the two sources are positionally coincident the TeV emission is suggestive of an extended object.

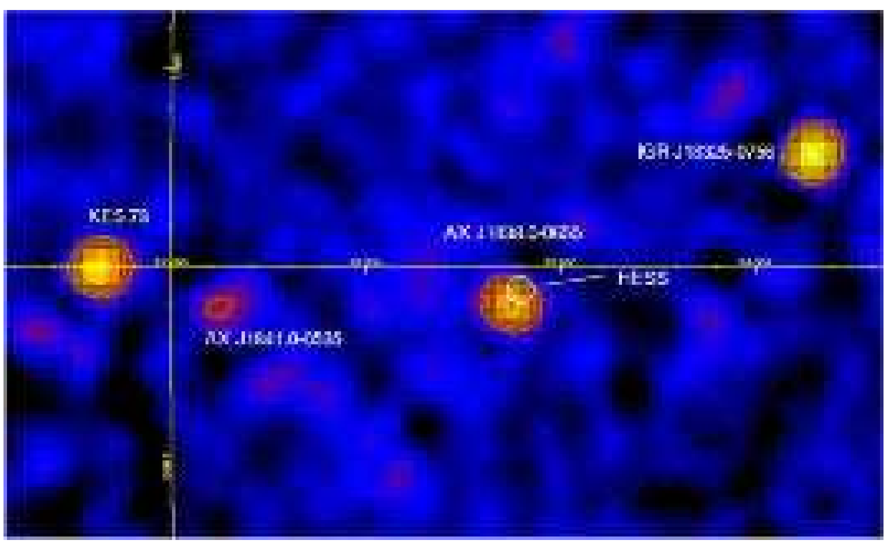

Fig. 2 The large IBIS sky region map containing AXJ1838.0-0655

the Galaxy plane, detected in the TeV range with a statistical significance of 7-8 σ. It is located at R.A.(2000)= 18h 37m 42.7s and Dec(2000)=-06 55 39 (error box of about 1-2') [1] and the estimated flux, above 200 GeV, is 9×10^{-12} photons cm^{-2} s^{-1}. The authors suggest AXJ1838.0-0655to be the candidate for HESS J1837-069, in view of the spatial coincidence.

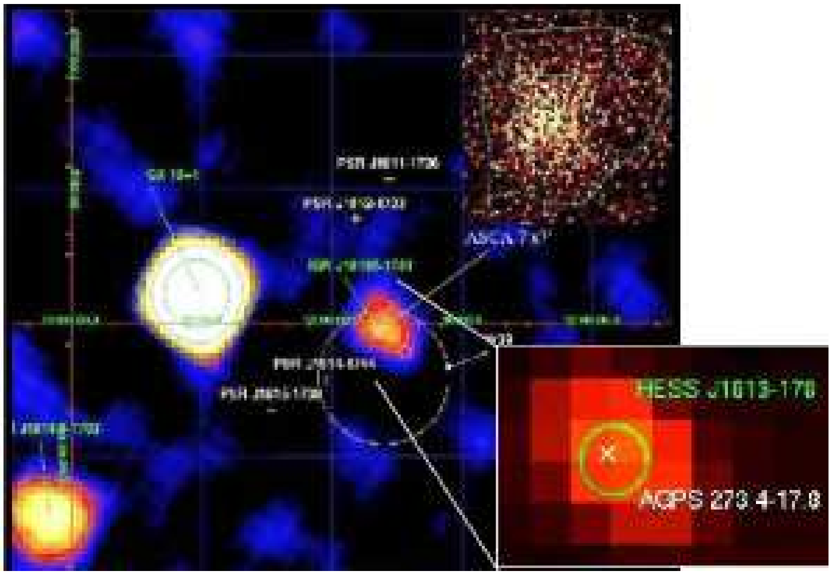

Fig. 3 From Ubertini et al. 2005. The IBIS/ISGRI 20-40 keV significance map showing the location of IGR J18135- 1751 and relative significance contours; the source spatial profile is compatible with the detector response to a point source. The extension of HESS J1813-178 as well as the position of AGPS273.4-17.8 are both contained within the internal IBIS/ISGRI contour. Also shown is the location (and extension) of W33, of the 4 nearest radio pulsars (PSR J1814- 1744,PSR J1812-1733, PSR J1815-1738 and PSR J1811-1736) and of the ROSAT source 1WGA J1813.7-1755 (white small diamond). The ASCA-SIS image is shown as an insert on the top right side of the figure: contour levels provide marginal evidence of extended emission. In the picture is also present GX13+1 and the transient source SAX J1818.6-1703 that are field sources not contaminating in any way IGR J18135-1751, in view of the large angular distance between the objects (see text for details). The coordinates are displayed in Galactic system [18]

AXJ1838.0-0655was discovered by the Einstein satellite in X-rays and named 1E1835.3-0658 [11] then observed by ASCA at higher energy during the Galactic plane survey [4] with a positional uncertainty of 1' in radius, basically coincident with the position of the original discovery. It was found to be bright in the 0.7-10 keV band at a flux level of 1.1×10^{-11} erg cm^{-2} s^{-1} and a hard (Γ=0.8) and absorbed (N_H=$4{\times}10^{22}$ cm^{-2}) power law shape. The summary of the observed positions for the different component, from soft X-ray to TeV range, is shown in Fig. 1 (see [14] for details). From the angular distribution it looks evident that the Einstein, ASCA and IBIS sources are the same emitting source which is also likely to be active at TeV energies. Finally, [14] report the presence of a strong radio source, TXS1835-069-CUL1835-06, associated in Simbad with a candidate supernova remnant, SNR025.3-00.1 [9], positioned at the side of the IBIS error box, though not compatible with ASCA/Einstein X-ray position. The X/gamma-ray data indicate a point source nature for this object, while the high energy results are more in line with an extended emission, (see Fig. 1) suggestive of a non-thermal radiation mechanism pointing to a SNR and/or a PWN [1]

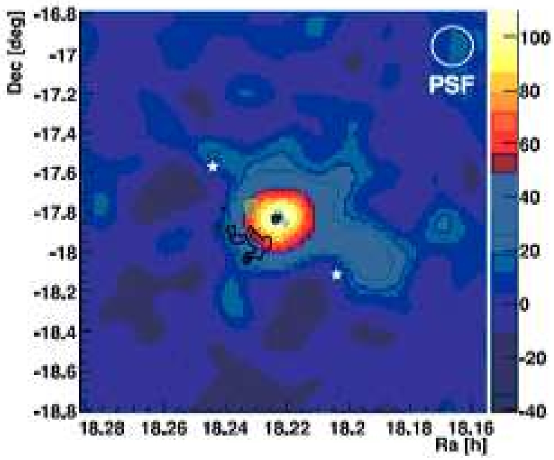

Fig. 4 From Albert et al. 2006. Sky map of gamma-ray candidate events (background-subtracted) in the direction of HESS J1813-178 for an energy threshold of about 1 TeV. Overlaid are contours of 90 cm VLA radio (black) and ASCA X-ray data (green) from Brogan et al. (2005). The two white stars denote the tracking positions W1, W2 in the wobble mode (see [3] for details).

3 HESS J1813-178 and IGR J18135-1751: same emitting region/mechanism?

IGR J18135-1751 was one of the newly discovered source during the compilation of the second IBIS/ISGRI survey catalogue [5]. It was immediately clear that the soft gamma-ray excess was positionally coincident with the very high energy source named HESS J1813-178, one of the 8 unknown sources found in the HESS survey of the inner region of the Galactic plane. The source position was found at R.A.(2000)=18h 13m 37.9s and Dec(2000)=-17° 50' 34" and has a positional uncertainty of 1-2 arcmin. The source was reported to be slightly extended, about 3 arcmin and had a statistical significance of about 9σ. Even if the source was reported to be quite bright 12×10^{-12} photons cm^{-2} s^{-1} above 200 GeV, it was impossible to find an evident counterpart. An archival search for soft X-ray data resulted in a possible counterpart in the ASCA archive data: AGPS273.4-17.8 at R.A.(2000)=18h 13m 35.8s and Dec(2000) = -17° 49' 43.35" with an associated uncertainty of 1'. In the X-ray band the source is fairly bright showing a 2-10 keV flux (corrected for absorption) of 1.8×10^{-11} erg cm^{-2} s^{-1} [18].

In Fig. 3 is shown the IBIS/ISGRI 20-40 keV map with the location of IGR J18135-1751. The authors report the relative significance contours to be 6 (for the external one), 8, 10, 20 and 40 σ, that are compatible with a point source. The extension of HESS J1813-178 as well as the position of AGPS273.4-17.8 are both contained within the internal IBIS/ISGRI contour. Also it is shown the location and the extension of W33 and the 4 nearest radio pulsars, namely PSR J1814-1744, PSR J1812-1733, PSR J1815-1738 and PSR J1811-1736. The combined IBIS-ASCA spectrum, obtained adding the two data set with-

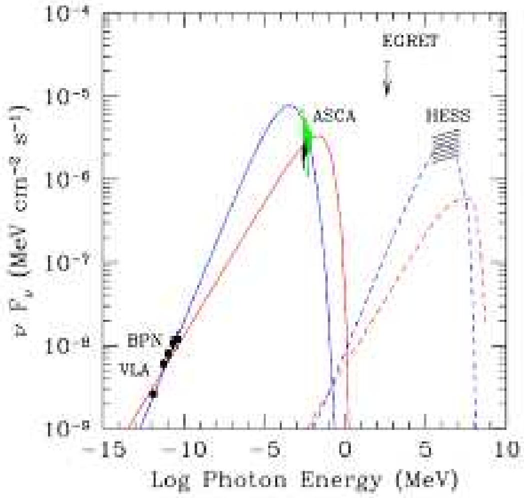

Fig. 5 From Brogan et al. 2005. Fits to the broadband emission of HESS/ASCA source assuming that all the flux originates from the shell of SNR G12.8 0.0. The diagonal black lines indicate both the uncertainty in the HESS flux measurements, and the fact that no spectral information has yet been published for the TeV emission. The two models indicated by the red and blue lines show the range of parameter space that best fit the data: the red model uses the spectral index from the best fit ASCA Nh of 10.8×10^{22} cm^{-2} (black X-ray spectrum), while the blue model uses the spectral index implied by the 1σ lower limit to Nh of 8.9 $\times10^{22}$ cm^{-2} (green X-ray spectrum). Both models include contributions from synchrotron (solid lines) and IC (dashed lines) mechanisms. The authors have assumed that the filling factor of the magnetic field in the IC emitting region is 15%.

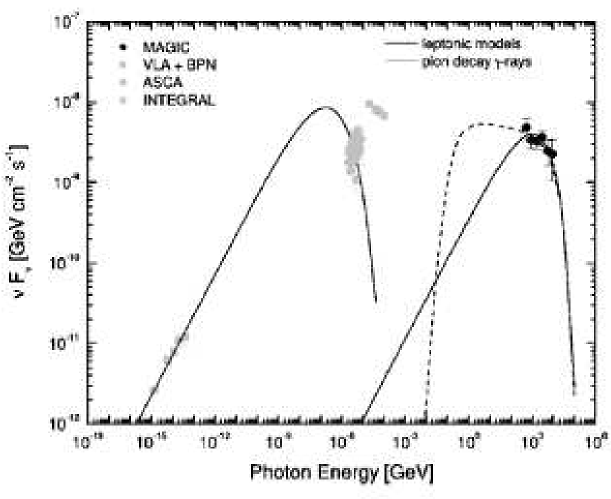

Fig. 6 From Albert et al. 2006. Leptonic and hadronic models for the J1813-178 data. Details are given in [3]. Radio data are from the VLA, Bonn, Parkes, and Nobeyama observatories [6]; X-ray and hard X-ray data are from ASCA [6] and INTEGRAL [18]

out the need of any normalisation, confirm that HESS J1813-178 has a point like X-ray counterpart with a power law emission from 2 to 100 keV and an associated radio counterpart. The data set is strongly suggesting that it is a non-thermal source, possibly accelerating electrons and positrons which radiate through synchrotron and inverse Compton mechanism. Brogan et. al. (2005) have provided a possible interpretation of the HESS/ASCA spectrum by fitting the broadband emission assuming that all the flux originates from the shell of SNR G12.8 (see Fig. 5 and [6], for a detailed description). The two proposed models (corresponding to two different Nh absorption values) are shown by the red and blue lines that provide the best fit to the data. The models include X-ray emission from synchrotron radiation (solid lines) and Inverse Compton processes (dashed lines), assuming a filling factor of 15% for the magnetic field in the IC emitting region. More recently the MAGIC experiment has observed HESS J1813-178, resulting in the detection of a differential gamma-ray flux consistent with a hard-slope power law, described as $\mathrm{d}N_\gamma/(\mathrm{d}A\mathrm{d}t\mathrm{d}E) = (3.3 \pm 0.5) \times 10^{-12}(E/\mathrm{TeV})^{-2.1\pm0.2}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{TeV}^{-1}$ [3]. The image of the MAGIC field containing the high energy excess is shown in Fig. 4. The authors quote the systematic error to be 35% in the flux level determination and 0.2 for the spectral index. Within errors, the flux was found steady in the timescales of weeks as well as in the year-long time span between the MAGIC and HESS pointings. They report a multiwavelength emission associated to HESS J1813-178, is shown in Fig. 6, including the MAGIC data at high energies. The authors compare the hadronic and leptonic emission models with the high-energy gamma-ray data (see [3] and [16] for details). The main conclusions are that for hadronic models the observed high energy luminosity ($2.5{\times}10^{34} ergs^{-1}$ at a distance of 4kpc) implies a matter density of $\sim$6 cm^{-3} assuming gamma-ray are generated in the whole Supernova remnant, an acceleration efficiency for the hadrons of $\sim$3% and a Supernova power of 10^{51} ergs with a target mass for relativistic particles of about 2 Solar masses (within or close to the SNR) to justify the observed luminosity.

For leptonic models, they assume relativistic electrons distribution of $\mathrm{d}N_e/(\mathrm{d}V\mathrm{d}E) = A_e(E/\mathrm{GeV})^{-\alpha_e}\exp\left(-E/E_{\mathrm{max,e}}\right)\ \mathrm{GeV}^{-1}\mathrm{cm}^{-3}$ and obtain good fits with value of α_e $\sim$2.0-2.1 $E_{\mathrm{max,e}}$ $\sim$20-30 TeV, assuming the cosmic microwave background as target photons. The best fit to the radio synchrotron emission is $\alpha \sim 2.0$ and require a magnetic field of 10 μG with a filling fraction of about 20% ([3]). This model is not very different from the blu one in Brogan et al. (see Fig. 5), even if a lower filling factor $E_{\mathrm{max,e}}$ is assumed.

4 Implication of the Synchrotron - Inverse Compton Scenario

The detection of soft gamma ray photons from TeV sources it is important to better understand the emission mechanisms and particle acceleration processes in SNR. In addition, the consistency with a power law of X-ray spectra, spanning from few to few hundred of keV, and the lack of X/gamma variability is compatible with a SNR or a Pulsar Wind Nebula, the latter not yet evident fom observational view point. As an example, HESS J1813-1751

has a very young remnant, of the order of 300 to 3000 year, assuming a density medium of $\sim$1 cm^{-3}. The IBIS detection of soft gamma ray photons up to $\sim$100 keV [19] in the Synchrotron - Inverse Compton Scenario force the lifetime of the emitting electrons to be quite short if compared to the one of the radiating electrons in the GHz frequency [12,8,19]. In fact, the lifetime for the high energy electrons is $t_{1/2} \sim 224 \times (B/10\mu G)^{-3/2}$ y. This model also imply the radio and X/soft gamma-ray synchrotron emission to be spatially coincident and X-ray emission that sharply drops behind the shock. Because of this effect, the X-ray photons will be confined close to the electrons acceleration region while the same electron population would eventually drift having a diffusion speed of a fraction of the light one. The detection of a substantial flux of soft gamma-rays from the HESS J1813-1751 region is supportive of the red fit model proposed by [6], that implies a lower ratio of peak emission frequencies $R_\nu = \nu_p^{IC}/\nu_p^{Sy}$ if compared with the blue one, not capable to fit the IBIS data and, in turn, not compatible with the single source scenario. Unfortunately, the red model is unable to fit the HESS data, the physical reason being the synchrotron losses, in the presence of a quite strong magnetic field predicted by the model, constraining the density of the electrons necessary to radiate via Inverse Compton interaction with the CMB radiation. The picture ameliorate considering that a substantially higher UV light flux could be supplied by W33, a close HII region. An energy density of $\sim$3 eV cm^{-3} could be easily provided, a factor $\sim$10 higher than the density of $\sim$0.26 eV cm^{-3} of the CMB photons [1] (for a detailed analysis of the IC model see [19]).

5 Conclusions

It is clear that both the hadronic and leptonic models so far proposed fails to easily explain the whole observational picture if the radio, X/soft gamma-rays and TeV high energy photons are produced in the same SNR region by a single physical process. In fact, to finally confirm the above hypothesis it is necessary to have instruments capable to provide spatially resolved spectroscopy with a fraction of arcsec. While in the X-ray range this seems to be possible with long CHANDRA exposures it is not with the present generation of gamma ray instruments in the best case providing arcmin angular resolution [13,17]. This will be achievable with a new generation of Gamma Ray Imagers providing at the same time a factor of 10 better sensitivity, as discussed in the present conference, as shown in Fig. 7. On a shorter time frame it could be possible to improve the lack of our knowledge in the blank region in between the soft gamma ray range covered by INTEGRAL and the very high energy one by HESS and MAGIC. In fact, the imminent launch of the Italian AGILE gamma-ray satellite, covering the 30 MeV-50 GeV range with a good sensitivity over a wide field of view, and GLAST in perspective, will be a powerful tool to finally disentangle the nature of the high energy sky.

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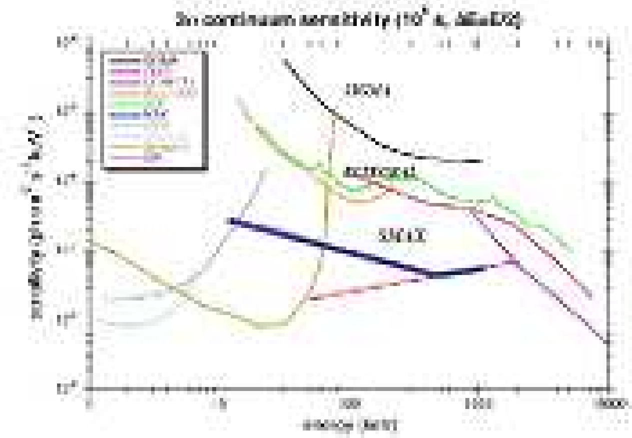

Fig. 7 The lap in sensitivity expected from new generation gamma ray observatorysuch as MAX+ or the newly prosed Gamma Ray Imager (GRI) based on Laue Lens complemented at lower energy by a large CZD detector (in the figure is shown the SMAX sensitivity, this conference)

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